Tuning Fuzzy Membership Functions to Improve Performance of Vector Control Induction Motor Drives

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***Abstract*— This paper presents an effective strategy for tuning of fuzzy membership functions based on fuzzy logic controller approach for a vector controlled induction motor drives for high performance applications. Initially, the input scaling factors are calculated based on known motor data and symmetrical triangular membership functions have been used for standard design. Then, asymmetrical convergent peak value positions of these membership functions have been considered to improve the control performance. The simulation test is done for low, half and full rated speed response and load disturbance for full rated speed. By tuned membership functions, the results demonstrate that the robustness and the effectiveness of fuzzy logic controller for high performance of induction motor drives system is achieved.**

***Index Terms*— Fuzzy logic controller; Induction motor; Membership functions.**

I. INTRODUCTION

The induction motors are the most commonly used in several industrial applications due to their reliability, less maintenance, and low cost. In the same time, industries demanded for high performance application in term of good dynamic response for changes in the load or in the command speed. Therefore to regulate the demands, vector control method can be used in induction motor drives. By using this method, the induction motor is run like a separately excited DC motor [1]. The advantages of the AC drives over DC drives are unaltered. Thus a drives system with a good dynamic response is developed. But, the design of speed controller is the most important part of electrical drives. A common speed controller of an induction motor is using conventional Proportional plus Integral (PI). The controller has a simple structure and can offer appropriate performance through various operations [2][3]. The use of PI controller is difficult due to changes of temperature, magnetic field, frequency and other factors. The PI controller with fixed gain is unable to provide the required actual performance, with these uncertainties especially in the presence of external load disturbances [4][5]. This behavior of the controller causes deterioration of drives performance.

In recent years, fuzzy logic controller (FLC) has shown high recognition in induction motor drives system for robustness performance. The system FLC has the advantage that it does not required detail mathematical model information of the system. Basically, the structure of FLC system consists of the knowledge base, fuzzification interface, inference engine, and defuzzification module. The knowledge base contains rule base and a data base. The rules base are in effect part of the procedure, because it determines the control strategies to be implemented, while the data base consisting of declarative knowledge section, which includes a membership function (MF) and scaling factors [6].

The FLC design fundamentally approaches the way of researchers' operation intuitiveness. This makes it attractive and easy to incorporate experimental rules that reflect the experience of human experts into the controller [7]. Hence, the tuning process of FLC through trial and error procedure is used to obtain optimal performance of the system. Therefore, it can cause time-consuming. Researchers found that the earlier determination of membership function shape and its optimum distribution is the best design for tuning FLC. [8].

This paper investigates the successful implementation of tuning membership functions to optimize the fuzzy speed control for a vector-controlled induction motor drives. The robustness of drives performance has been evaluated under load disturbance condition. The performance criteria, such as transient response, undershoot and recovery time due to load disturbance has been considered for performance evaluation.

II. INDUCTION MOTOR DRIVE WITH FUZZY LOGIC CONTROL

The block diagram of the induction motor drive with FLC is shown in Figure 1. The d-axis current reference i_{ds}^{*}, can be calculated from the flux command φ_{dr}^{*} denotes the right rotor flux command for every speed reference within the nominal value. The rotor speed reference ω_m^{*} is compared with measured rotor speed ω_m and FLC processed the resulting error to produce q-axis reference current i_{qs}^{*}. Both i_{ds}^{*} and i_{qs}^{*} are converted to three phase stationary reference frame through Inverse Park's Transformation and compared to the current from the feedback of the motor. Then the current errors are fed to hysteresis current controllers which generate switching signal for the inverter [9].

The configuration of FLC can be represent as Figure 2 of the input linguistic variables; the speed error, *e* and change in speed error, *ce* and the output linguistic variable; the torque producing current component, i_{qs}^* . The correlation function of FLC can be expressed as [10]:

$$i_q(n) = \int_{discrete} \Delta i_q(n) = f\left(\Delta e(n), \Delta\omega_m(n)\right) \quad (1)$$

and the change of speed error can be written as:

$$\Delta e(n) = \Delta\omega_m(n) - \Delta\omega_m(n-1) \quad (2)$$

The present sample of speed error is:

$$\Delta\omega_m(n) = \omega_m^*(n) - \omega_m(n) \quad (3)$$

where $\omega_m(n)$ is motor actual speed, $\omega_m^*(n)$ is past sample of reference speed and f represents the nonlinear function.

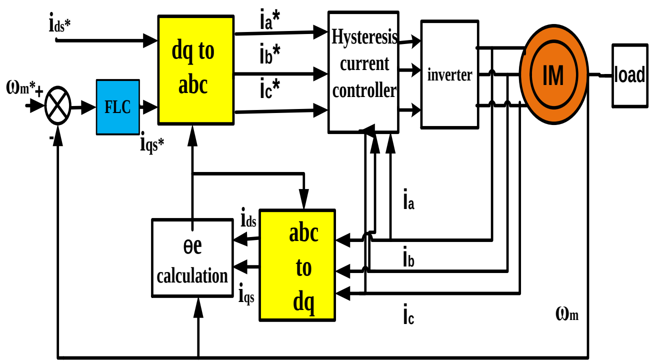


Figure 1: Induction motor drive with FLC

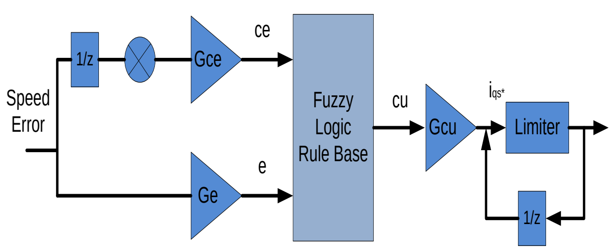


Figure 2: Fuzzy logic controller

III. Fuzzy Logic Controller Design

The main objective of the control system is to determine the effectiveness of the proposed FLC by reducing the complexity of tuning MF for high performance induction motor drive by provided that the suitable torque producing current component i_{qs}^* dependent on the operating conditions. Researchers [11] studied that triangular type of MF is the best for fuzzy controlled drive system. Therefore in this study, FLC is considered using triangular MF type for both inputs and outputs.

A. Scaling Factors

The consideration of the input and output of the scaling factors G_{ce}, G_e and G_{cu} are very important for FLC because a change of scaling factors can affect the stability, oscillation and damping of the system. Hence, the input of scaling factors G_{ce} and G_e were calculated using known motor data. [12][13][14]. Given that maximum speed of this motor is 184.3rad/s. Therefore, G_e is 0.0054256 and tuned G_{ce} is 2.2385. Output scaling factor is set to G_{cu}=2.

B. Fuzzy Rules

"IF….THEN rules introduced by Mamdani were used in this work because it can provide a normal context to adapt the human knowledge into fuzzy. These statements governing the relationship between inputs and outputs variables in terms of membership functions. In this stage the input variables *e* and *ce* are processed by the inference engine that implements the rule base of 49 rules presented in Table 1. [15] The linguistic terms used for inputs and output variables are defined as: NL is Negative Large, NM is Negative Medium, NS is Negative Small, ZE is Zero Error, PS is Positive Small, PM is Positive Medium and PL is Positive Large.

Table 1
Rule Base for FLC

e	ce						
	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

C. Membership Function

The triangular membership function used for standard design is shown in Figure 3. Seven triangular membership functions are used to denote the input and output FLC variables. The triangular membership functions are designed to be symmetrical and identical in terms of width and peak position.

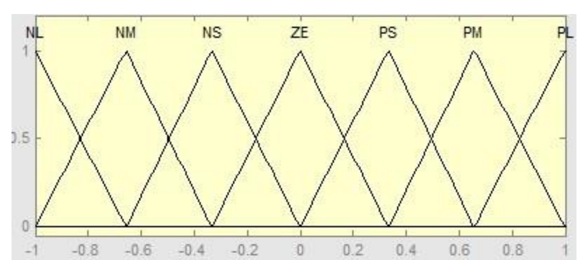
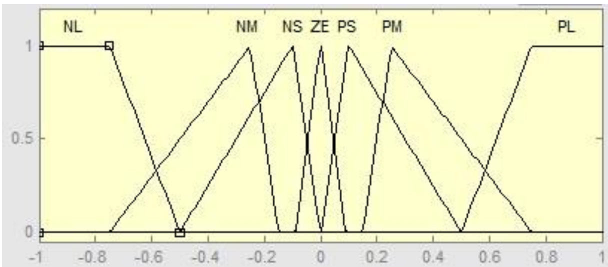
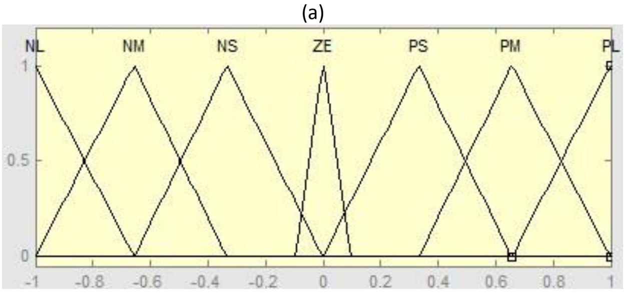


Figure 3: Triangular membership function for standard design

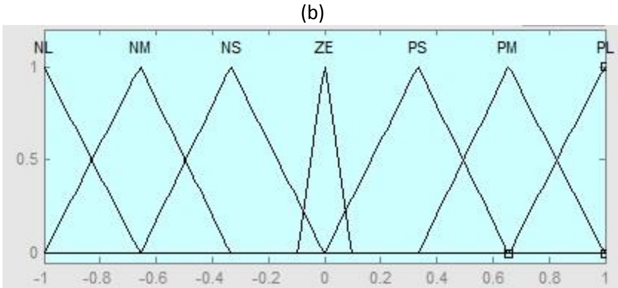
However, to improve the control performance in term of rise time and settling time for large speed command and load rejection, the position of peak value of the membership functions can be altered [16]. The speed error membership functions namely as NL, NM, NS, ZE, PS, PM and PL are modified to improve the drive behaviour especially in the vicinity of the set point. Tuning the width and moving the peak value positions of these membership functions towards the ZE value will cause the speed controller to be more sensitive to a small change in speed error and produce a large control. Figure 4 shows the altered membership functions for optimize performance.



(a)



(b)



(c)

Figure 4: Tuned MF for (a) speed error, (b) change in speed error and (c) change in q-axis reference current

D. Defuzzification

Generally the output of fuzzy controller has to be translated into a crisp value by using defuzzification technique. In this work, the center of area (CoA) method is used

IV. Results And Discussion

Several simulation tests of standard triangular and tuned membership function of based vector control of induction motor were presented using MATLAB/SIMULINK. The motor used in the simulation is 415V, 3 phase, and 1.5hp squirrel cage induction motor. The parameters of the motor are given in Table 2. For this simulation, the reference flux is taken as 0.54Wb and starting torque is limited to 15Nm. For hysteresis current controller, the hysteresis current band is set constant and equal to ±0.5 A. DC Voltage supply limit to 400V.

Figure 5 shows the comparison of speed response of standard MF and tuned MF using FLC controller with a speed command of 1760rpm with no load condition. The standard MF shows 0.01s delay compared to tuned MF to achieve a steady state. It is evidence from Figure 5 that the performance of tuned MF is better than standard MF under no load condition. The system also tested for half rated and low speed demand performance as described in Figure 6 and Figure 7.

Table 2
Induction motor parameters

Parameter	Value
Stator resistance, R_s	8.67 Ω
Rotor resistance, R_r	0.6167 Ω
Stator inductance, L_s	0.5285 H
Rotor inductance, L_r	0.5285 H
Mutual inductance, L_m	0.4952 H
Moment of inertia, J	0.00821 Kgm2
Number of poles	4

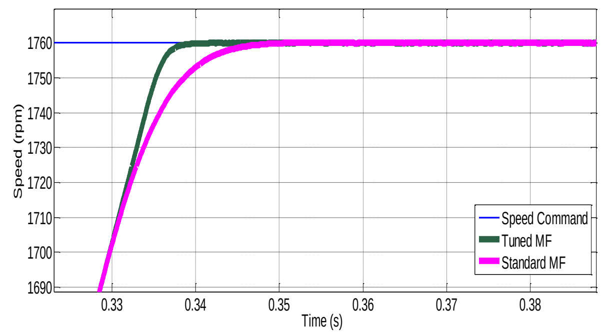


Figure 5: Speed response of the drive using standard and tuned MF at rated speed of 1760rpm

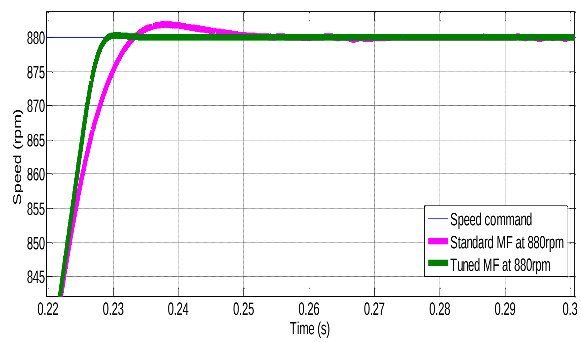


Figure 6: Speed response of the drive using standard and tuned MF at half rated speed of 880rpm

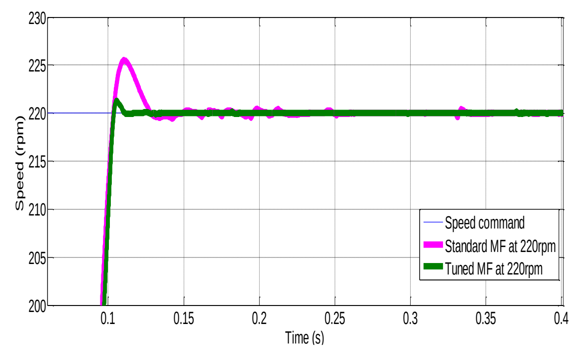


Figure 7: Speed response of the drive using standard and tuned MF at low speed of 220rpm

Figure 6 shows the speed response of IM when the speed command is half rated speed (880rpm). The rise time of speed response is very fast for Tuned MF compared to standard MF. The tuned MF achieved steady state at 0.235s meanwhile standard MF reached steady state at 0.255s. For slow speed demand, 1/8 rated speed is considered in the simulation test. The speed response in Figure 7 shows the comparison between tuned and standard MF for 220rpm speed command of IM. The tuned MF contributed less overshoot compared to standard MF.

In order to test robustness of the drives system, the performance of standard MF and tuned MF is investigate under load condition for half and full rated load as depicted in Figure 8 and Figure 9 respectively.

Figure 8 shows that tuned MF gives better response in term of less undershoot at t=0.5s and able to stable again after several millisecond (2ms). Then, Figure 9 shows a dip of 5 rpm is formed for tuned MF compared to standard MF where the dip is 9 rpm. The tuned MF recovers slightly faster than standard MF that is about 5ms. It can be clearly seen that the tuned MF produces less undershoot response compared to the standard MF during load disturbance and shorter recovery time.

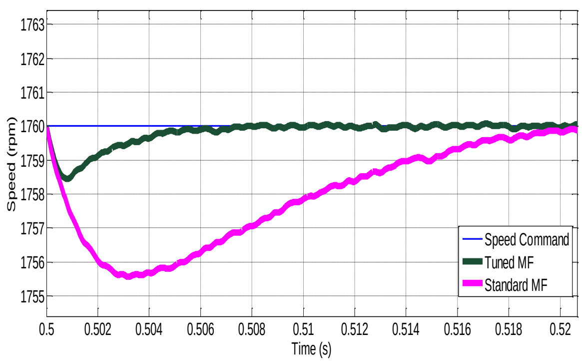


Figure 8: Load disturbance rejection of standard and tuned MF at half rated load, 3Nm

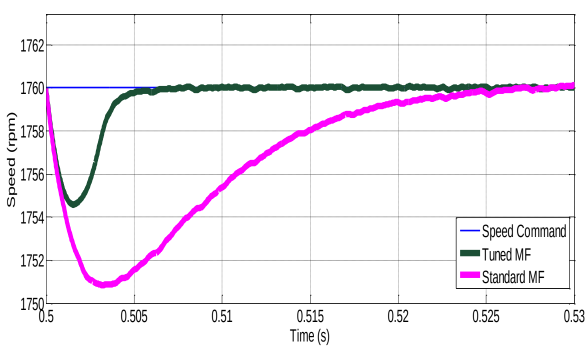


Figure 9: Load disturbance rejection of standard and tuned MF at full rated load, 6Nm

V. CONCLUSION

In this paper, induction motor drives with fuzzy logic controller were described. The drive system was simulated with standard triangular MF and tuned asymmetrical MF. The drive performance has been evaluated for low, half and full rated speed response and load disturbance rejection for full rated speed. It has been observed that the tuned MF improved the performance of FLC in term of transient response and load disturbance rejection compared to standard MF. Therefore, by tuning MF for FLC in the drives system can increase the robustness of the system. Thus, the high performance of the drives can be achieved.

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